ADBI Working Paper Series

ELECTRIC VEHICLES AND ENERGY INSECURITY IN ASEAN COUNTRIES: RENEWABLE ENERGY INTEGRATION AND URBAN AIR QUALITY

Youngho Chang and Yanfei Li

No. 1025
October 2019

Asian Development Bank Institute

Youngho Chang is a senior lecturer at the School of Business of Singapore University of Social Sciences in Singapore. Yanfei Li is a research fellow at the Economic Research Institute for ASEAN and East Asia in Indonesia.

Suggested citation:

Chang, Y. and Y. Li. 2019. Electric Vehicles and Energy Insecurity in ASEAN Countries: Renewable Energy Integration and Urban Air Quality. ADBI Working Paper 1025. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/electric-vehicles-energy-insecurity-asean-countries

Please contact the authors for information about this paper.

Email: yhchang@suss.edu.sg

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

The electrification of road transport in the ASEAN appears to decrease the level of final energy consumption in the road transport sector in 2040. The level of primary energy consumption, however, may not decrease unless countries adopt aggressive policies toward the integration of renewable energy into electricity generation. This study presents the consequences of the electrification of road transport in the ASEAN in terms of various energy dimensions, namely primary and final energy consumption, the integration of renewable energy, the importing of fossil fuels, and the levels of carbon dioxide and sulfur dioxide emissions. Taking the emissions of sulfur dioxides as an indicator of the urban air quality, this study investigates whether and how the electrification of road transport helps to enhance the status of energy insecurity by improving the urban air quality. The findings of this study suggest the need to implement an aggressive fuel mix policy for electricity generation with a strong drive for electric mobility.

Keywords: electric mobility, urban air quality, sulfur dioxide, ASEAN, fuel mix policy for electricity generation

JEL Classification: N75, Q40, Q42, Q48

Contents

1. INTRODUCTION

The electrification of transportation (or electric mobility) appears to be the mainstream or a game changer in road transport. Many countries of the Association of Southeast Asian Nations (ASEAN) are promoting the electrification of road transportation or electric mobility. Mainly economic and energy-related benefits drive this interest, but the consequences of electric mobility could extend beyond the economic and energy-related benefits. The reduction of primary energy consumption due to higher levels of electric mobility will result in the reduction of air pollutants, such as carbon dioxide or sulfur oxide emissions, which in turn will improve the air quality in the urban environment. The electrification of transportation such as buses can reduce the amount of carbon dioxide emissions by 1 million tons per year (Li and Chang 2019).

People consider energy insecurity a way of verifying the relationship between energy, the built environment, and health in relation to climate change (Hernandez 2013, 2016). Lower access to energy causes deterioration of the built environment, which in turn has significant negative repercussions for health or public health. The higher the level of electric mobility penetration is, the lower the level of pollutant emissions is. If all other things are equal, a lower level of pollutant emissions means an improvement in the urban air quality.

The National Development and Reform Committee (NDRC) in the People's Republic of China (PRC) circulated draft Administrative Rules on Auto Industry Investment on 17 May 2018. The draft rules aim to reduce investments in internal combustion engine-driven vehicles and boost investments in electric vehicles. Once fully enacted, the draft rules will encourage investment in and promote technological progress in electric vehicles, among others.

The electrification of road transport not only facilitates more mobilization but reduces urban air pollution, as it decreases tailpipe pollution provided that renewable energy accounts for a substantial share of the electricity generation. Early adoption of electric vehicles seems to be possible, but little research has examined how this will affect the energy and environmental sphere in the ASEAN (Li and Chang 2019).

Electric vehicles (EVs) can solve transport problems and spearhead technological dominance, especially in transportation technologies. The so-called EV drive in the PRC is a good example of the effort to become a technological pioneer. Other examples are the developing technologies of autonomous driving or artificial intelligence that many tech firms, such as Google, Amazon, Apple, and Tesla, are pursuing.

Using the projections of EVs and the electrification of road transport (e.g., Li and Chang 2019), this study aims to show how electric mobility affects the urban air quality in the ASEAN and alleviates the consequences of energy insecurity. It also aims to determine how the integration of renewable energy into the power grid affects the urban air quality and mitigates the negative consequences of energy insecurity.

The remainder of the study proceeds as follows. Section 2 presents the relationship between energy use, urban air quality, and health and explains the choice of sulfur oxides as a proxy indicator for urban air quality to examine the possible relationship between energy insecurity and health. Section 3 shows the status of and projected figures for road electrification in the ASEAN. Following this, section 4 describes how electric mobility affects primary energy consumption in the ASEAN countries. Section 5 examines the main theme of this study, whether and how electric mobility improves the urban air quality, taking the level of sulfur dioxide emissions as an indicator of energy insecurity representing the nature of public health. Section 6 concludes this study.

2. ENERGY USE, URBAN AIR QUALITY, AND IMPLICATIONS FOR HEALTH

Energy acts as an input for production in an economy. It enables the economy to function properly and grow. At the same time, the use of energy produces pollutants as by-products, such as particular matter 10 micron (PM_{10}), particular matter 2.5 micron ($PM_{2.5}$), nitrogen oxide (NO_2), ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2), and sulfur oxides (SO_2), among others. This is how the energy use affects the urban air quality. The greater the use of energy, the larger the amounts of air pollutants emitted. The emitted air pollutants stay in the atmosphere for a while, increase the concentration level of the pollutants, and eventually affect the health of the inhabitants in the economy.

The characteristics, sources, concentrations, and behavior of these pollutants in the atmosphere are the key subjects of urban air pollution-related studies (e.g., Barkley et al. 2017; Hasan et al. 2014; Hosamane and Desai 2013; Khan et al. 2017; Mansouri, Hoshyari, and Mansouri 2011; Nikolic et al. 2010; Szyda et al. 2009; Xiao et al. 2018) along with ways to improve the urban air quality (Buckley and Mitchell 2011; Nowak, Crane, and Stevens 2006). These studies have presented the key sources of air pollutants and the trend of air quality in urban areas, among others. The level of SO_2 in the atmosphere is apparently highly correlated with the heating season in Seoul, Republic of Korea (Khan et al. 2017), in Chengdu, PRC (Xiao et al. 2018), and in Shiraz, Iran (Mansouri et al. 2011) and with coal production and traffic intensity in Poland (Szyda et al. 2009).

There are prolific studies on regional urban air quality (e.g., Alpopi and Colesca 2010; European Environmental Agency (EEA) n.d.; International Gas Union 2016). A comparative study of urban air quality in European capital cities presented the steel industry, oil refining, motor vehicles, and power generation as the key sources of SO_2 (Alpopi and Colesca 2010). Power generation and domestic dwellings are the major stationary sources of SO_2 in Europe (EEA n.d.). Urban air pollution, however, may not hurt the economy much if it makes extensive use of a cleaner fossil fuel, such as natural gas, rather than coal in power generation and heating (International Gas Union 2016).

Urban air pollution is one of the main threats to health at the global scale (International Gas Union 2016; WHO 2000, 2005). Whether and how urban air pollution affects health in an economy have been the subject of extensive studies (e.g., International Energy Agency 2016; Kosan et al. 2018; Perera 2018; Prescott et al. 1998; Qin et al. 2017; World Resources Institute 1988). Urban air pollutants, such as particulate matters, sulfur dioxides, and ozone, appear to pose serious health damage and risks (World Resources Institute 1998). There seems to be a statistically significant and strong association between urban air pollution and cardiac and pulmonary disease (Prescott et al. 1998). A study has pointed out pollutants from the combustion of fossil fuels as a leading environmental threat to children's health and their future at the global scale (Perera 2018). The development of a new energy source, such as synthetic natural gas in the PRC, however, appears to benefit the households with the smallest carbon footprints (Qin et al. 2017).

Researchers understand the level of SO_2 concentration in the atmosphere has a strong correlation with urban transport (e.g., Afif et al. 2008; Ilyas 2007). A study has highlighted long-range transport as the key source in the variation of SO_2 concentration in Beirut (Afif et al. 2008), and there is a belief that air pollutants from motor vehicles are the main contributor to urban air pollution in Pakistan (Ilyas 2007).

There is a strong positive relationship between energy use and air pollution levels (e.g., ADB 2006; International Energy Agency 2016; National Academy of Engineering and National Research Council 2008; Wuebbles and Sanyal 2015). A cleaner energy world is a possible solution to improve the air quality and climate change (Wuebbles and Sanyal 2015). Another stream of research on the relationship between energy use and air pollution has indicated that the poor air quality due to energy use, such as haze, appears to hinder the performance of photovoltaics (Peters et al. 2018).

The analysis of the effect of electrifying vehicles and equipment on urban air quality presents a modest impact of electrification on the urban air quality in the US (Nopmongcol et al. 2017). The adoption of electric vehicles (EVs) or plug-in electric vehicles (PEVs) is likely to decrease air pollutants. The exact level of the contribution is dependent on how electricity is generated, where it is generated, and how people use the vehicles, but the current grid specification may cause the level of SO_2 emissions in Texas to increase (Nichols, Kockelman, and Reiter 2015).

Among various air pollutants, sulfur oxides (SO_2) are one of the main urban air pollutants. Transportation and power generation that uses fossil fuels are pointed out as the main sources of SO_2. As a way of decreasing SO_2 emissions, the PRC has explored a trading scheme for SO_2 emissions (Yang and Schreifels 2003) and is implementing it across the PRC.

This study takes sulfur oxides as a proxy indicator of the urban air quality. The following sections present the way in which electro mobility in the ASEAN countries changes the fuel mix of power generation and the number of various types of vehicles, including electric vehicles. Using the forecast numbers of all vehicles and primary energy consumption in 2040, this study investigates whether and how electric mobility improves the urban air quality and alleviates the negative consequences of energy insecurity as well as suggesting policy implications for decreasing energy insecurity.

3. ELECTRIFICATION OF THE ROAD TRANSPORT SECTOR IN THE ASEAN: OUTLOOK IN 2040

The ASEAN countries are expected to achieve the electrification of road transport by adopting appropriate policies (Li and Chang 2019). Changes in the primary energy consumption and the emissions of air pollutants, such as carbon dioxide or sulfur dioxide, will realize the possible impacts of such a transition.

The statistics of the transport sector in the ASEAN countries suggest how the electrification of the road transport sector affects the dependence on fossil fuel imports in these countries. As the transport sector typically accounts for 30% or more of the total primary energy consumption in the ASEAN countries, the expectation is that the impacts will be significant (Li and Chang 2019).

This study adopts the baseline scenario of the road transport sector in the ASEAN in 2040 that Li and Chang (2019) developed. The baseline scenario reflects various transport-related and economics-related data. These include the number of vehicle fleets, fuel consumption by road transport, fuel economy of various fleets, including electric vehicles, and fuel mix of power generation, which are transport related. Other data included are the outlook for the future economy and energy consumption, the fuel mix of the power sector, changes in the share of fleets in the total vehicle population and the amount of vehicle ownership, the outlook of the road transport sector in the ASEAN, including the number of vehicles in various fleets, and the corresponding level of fuel consumption.

Following the baseline scenario, the study adopts four scenarios to analyze the impact of introducing electric vehicles, together with other possible policies, such as aggressive fuel economy policies for both fossil fuel-based and conventional vehicles and aggressive policies toward cleaner power generation in the power sector. Table 1 shows the four scenarios with brief descriptions.

Table 1: Scenario Definition

Scenarios	Definitions
2040 BAU	Baseline projections on vehicle numbers and fuel consumption
2040 EV10	10% of the projected number of vehicles are EVs
2040 EV30	30% of the projected number of vehicles are EVs
2040 EV10 + FE	10% of the projected number of vehicles are EVs + aggressive fuel economy standards
2040 EV30 + FE	30% of the projected number of vehicles are EVs + aggressive fuel economy standards

Source: Li and Chang (2019).

Due to the deep penetration of EVs into the vehicle population in the future, the road transport sector needs strong support from the power generation sector. To capture the feedback between the two sectors, the scenarios include two sets of policy alternatives so that they can reflect the possible impacts of the policies on the fuel mix in the power generation. The study applies a set of power sector alternative policy scenarios (APSs) to the abovementioned scenarios. The APSs will presumably make the power generation cleaner or greener. The APS case states the target of an annual improvement of 3.7% in a fuel economy and in turn its achievement between 2015 and 2030 (GFEI and IEA 2017).

The GFEI and IEA report shows, however, that non-OECD countries achieved an annual improvement of 0.8% in the fuel economy during the period from 2005 to 2015, while OECD countries experienced an annual improvement of 1.8% during the same period. The fuel improvement in the BAU scenario is hence assumed to be 0.8% until 2030 and the same for the period from 2030 to 2040. The study applied the non-OECD rate of 0.8% to all the countries except for Brunei Darussalam and Singapore and the OECD rate of 1.8% to Brunei Darussalam and Singapore.

It is worth noting that the data relating to the number of vehicle fleets in the ASEAN and the level of corresponding fuel consumption are highly fragmented. Therefore, even the best effort to collect data from various sources, such as the literature, public databases, government reports, and news reports, has left room for improvement in data collection. Better data could make the best available estimation possible.

Table 2 presents the number of vehicles in various fleets in the ASEAN countries in 2015, while Table 3 presents the estimated fuel consumption levels in 2015.

Table 2: Number of Vehicles in Various Fleets in the ASEAN Countries in 2015
(Unit: Thousand)

	Bru	Cam	Indo	Lao	Mal
Passenger Cars	277.02	28.28	13,480.97	5.18	12,180.29
Trucks	20.29	6.84	6,611.03	55.72	1,177.44
Buses	2.37	0.44	2,420.92	63.01	72.49
Motorcycles	6.83	326.78	98,881.27	1,531.97	12,289.03
Total	306.51	362.34	121,394.19	1,655.88	25,719.25
	Mya	**Phil**	**Sing**	**Thai**	**Viet**
Passenger Cars	521.08	4,037.07	604.72	13,290.47	971.93
Trucks	214.26	24.68	162.18	982.70	870.32
Buses	30.43	28.80	17.74	142.86	157.75
Motorcycles	5,276.68	4,616.06	143.90	20,395.93	45,164.71
Total	6,042.45	8,706.61	928.54	34,811.97	47,164.71

Source: Li and Chang (2019).

Table 3: Fuel Consumption in the Road Transport Sector in the ASEAN in 2015
(Unit: Liter)

	Bru	Cam	Indo	Lao	Mal
Passenger Cars	424,635,527.7	20,574,918	8,796,550,000	3,417,540	14,470,200,500
Trucks	91,569,160.12	14,660,379.24	12,179,986,439	108,204,595	4,118,882,720
Buses	35,482,894.34	3,438,411.53	19,018,022,231	521,306,740	1,270,042,254
Motorcycles	3,630,345.73	79,298,376.05	21,330,889,695	336,945,481	5,197,872,767
Total (Mtoe)	0.47	0.10	53.83	0.86	21.36
	Mya	**Phil**	**Sing**	**Thai**	**Viet**
Passenger Cars	340,924,500	6,574,974,714	983,136,000	14,367,700,471	638,251,086.2
Trucks	412,789,539	118,355,056.2	761,330,957	3,128,201,737	1,682,920,994
Buses	323,330,408	761,600,000	440,657,053	2,191,210,856	1,351,522,097
Motorcycles	1,151,368,711	2,276,687,314	79,671,837.8	7,261,453,351	9,505,862,419
Total (Mtoe)	1.92	8.19	1.99	22.93	11.25

Source: Li and Chang (2019).

Table 4 presents the status of power generation in the ASEAN power sector as of 2015. It is worth noting that the fuel mix in the power sector and the conversion efficiency appear to affect the analysis of EV penetration significantly.

Four main factors appear to determine the number of vehicle fleets in the ASEAN countries by 2040. They are the GDP, population, vehicle ownership per 1,000 persons, and changing mode of road transportation. The vehicle ownership typically seems to reach a saturated level at a certain time. The changes in the share of fleets in the total vehicle population are caused by changes in the level of economic development, the structure of the economy, and the level of income. Table 5 presents the projected number of vehicles in 2040.

Table 4: Profile of the ASEAN's Power Generation in 2015
(Output in MWh)

	Bru	Cam	Indo	Lao	Mal
Coal	0	2,128,000	130,508,000	2,260,000	63,474,000
Natural Gas	3,738,860	0	58,894,000	0	69,962,000
Oil	37,880	228,000	19,650,000	0	1,739,000
Hydro	0	2,000,000	13,741,000	15,510,000	14,167,936
Others	0	41,000	10,536,754	0	1,024,000
Overall Average Thermal Efficiency	26%	32%	32%	35%	37%
Carbon Intensity kg/kWh	0.68	0.44	0.68	0.09	0.53
	Mya	**Phil**	**Sing**	**Thai**	**Viet**
Coal	0	36,686,000	602,885.01	32,917,000	51,002,000
Natural Gas	6,511,000	18,878,000	47,899,863.8	117,006,000	44,930,000
Oil	55,230	5,859,600	351,932.87	1,676,161.5	295,000
Hydro	14,167,936	8,665,000	0	5,748,000	63,194,000
Others	1,024,000	12,324,500	1,550,704.23	8,358,000	393,000
Overall Average Thermal Efficiency	28%	39%	49%	44%	41%
Carbon Intensity kg/kWh	0.20	0.47	0.36	0.42	0.34

Source: Li and Chang (2019).

Table 5: Number of Vehicles in Various Fleets in ASEAN Countries in 2040
(Unit: Thousand)

Type	Bru	Cam	Indo	Lao	Mal
Passenger Cars	526.51	522.17	21,062.91	1,167.08	15,875.14
Trucks	38.558	3.19	10,329.19	7.14	1,534.61
Buses	4.51	3.72	3,782.49	8.32	94.48
Motorcycles	12.99	597.06	154,493.81	1,334.46	16,016.86
Total	582.57	1,126.14	189,668.38	2,516.99	33,521.08
Type	**Mya**	**Phil**	**Sing**	**Thai**	**Viet**
Passenger Cars	3,933.97	9,117.23	1,306.52	17,156.91	23,600.28
Trucks	290.88	674.13	350.40	1,268.59	1745.02
Buses	42.29	98.01	38.33	184.43	253.69
Motorcycles	6,037.18	13,991.56	310.90	26,329.49	36,217.66
Total	10,304.31	23,880.93	2,006.15	44,939.42	61,816.64

Source: Li and Chang (2019).

The projection of vehicles in 2040 assumes that there will be some progress in the fuel economy of conventional vehicles using fossil fuels in the ASEAN countries. Table 6 presents the fuel economy of conventional vehicles in 2040.

Table 6: Fuel Economy of Conventional Vehicles in 2040

Fuel Efficiency/Economy (2040) BAU	Brunei Darussalam	Cambodia	Indonesia	Lao PDR	Malaysia
km/L (passenger car: gasoline)	17.20	14.27	13.74	14.27	15.23
km/L (truck: diesel)	13.31	11.05	10.64	11.05	11.79
km/L (bus: diesel)	5.48	4.13	3.75	3.54	3.21
km/L (motorcycle: gasoline)	36.28	31.29	31.29	31.29	31.29
Fuel Efficiency/Economy (2040) BAU	**Myanmar**	**Philippines**	**Singapore**	**Thailand**	**Viet Nam**
km/L (passenger car: gasoline)	14.27	12.95	17.20	14.09	14.27
km/L (truck: diesel)	11.05	10.03	13.31	10.91	11.05
km/L (bus: diesel)	2.73	2.48	3.29	3.09	3.40
km/L (motorcycle: gasoline)	31.29	31.29	36.28	31.29	31.29

Source: Li and Chang (2019).

Table 7 presents the fuel economy for electric vehicles, which will remain the same as it is now. The reason for this is that the electric drive trains are seemingly mature technologies.

Table 7: Fuel Economy of Electric Vehicles

Fuel Efficiency/Economy (2040) BAU	Brunei Darussalam	Cambodia	Indonesia	Lao PDR	Malaysia
km/kWh (passenger car)	5.44	5.44	5.44	5.44	5.44
km/kWh (truck)	0.80	0.80	0.80	0.80	0.80
km/kWh (bus)	0.81	0.81	0.81	0.81	0.81
km/kWh (motorcycle)	25	25	25	25	25
Fuel Efficiency/Economy (2040) BAU	**Myanmar**	**Philippines**	**Singapore**	**Thailand**	**Viet Nam**
km/kWh (passenger car)	5.44	5.44	5.44	5.44	5.44
km/kWh (truck)	0.80	0.80	0.80	0.80	0.80
km/kWh (bus)	0.81	0.81	0.81	0.81	0.81
km/kWh (motorcycle)	25	25	25	25	25

Source: Li and Chang (2019).

The APS scenarios assume that there will be aggressive improvements in the fuel economy of the motor vehicles, which are based on the targets that the GFEI and IEA (2017) set. Table 8 presents the levels of fuel economy that the ASEAN countries should achieve in 2040.

The table projects the level of energy consumption along with the level of electric mobility following these assumptions of road transport-related and fuel economy data.

Table 8: APS Case of Fuel Economy of Conventional Vehicles in 2040

Fuel Efficiency/Economy (2040) APS	Brunei Darussalam	Cambodia	Indonesia	Lao PDR	Malaysia
km/L (passenger car: gasoline)	22.69	21.83	21.03	21.83	23.31
km/L (truck: diesel)	17.57	16.90	16.28	16.90	18.05
km/L (bus: diesel)	7.24	6.32	5.74	5.41	4.91
km/L (motorcycle: gasoline)	47.88	47.88	47.88	47.88	47.88
Fuel Efficiency/Economy (2040) APS	Myanmar	Philippines	Singapore	Thailand	Viet Nam
km/L (passenger car: gasoline)	21.83	19.82	22.69	21.56	21.83
km/L (truck: diesel)	16.90	15.35	17.57	16.69	16.90
km/L (bus: diesel)	4.18	3.79	4.34	4.72	5.20
km/L (motorcycle: gasoline)	47.88	47.88	47.88	47.88	47.88

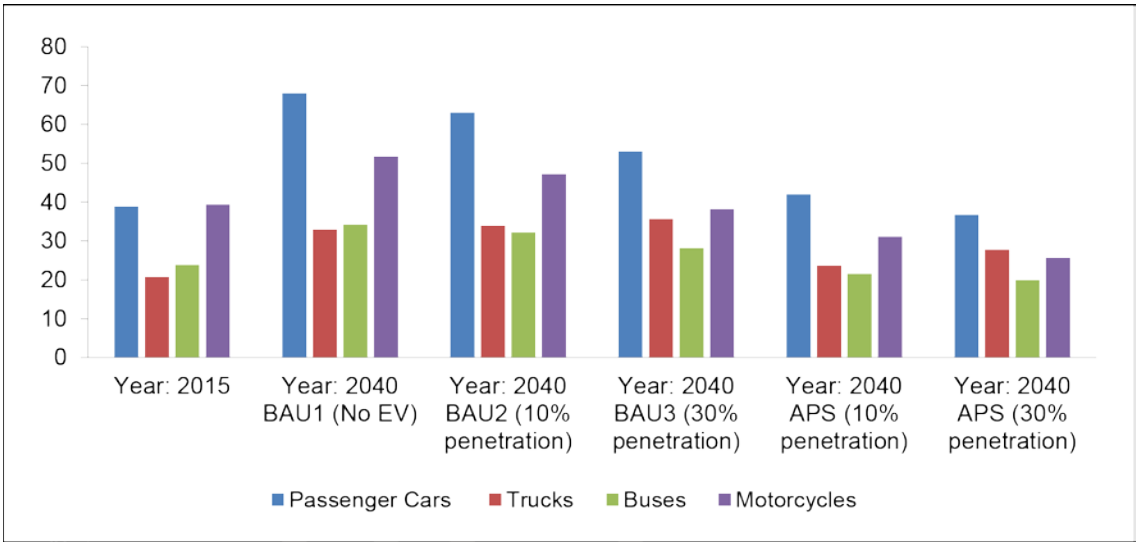
Source: Li and Chang (2019).

4. ELECTRIC MOBILITY AND ENERGY CONSUMPTION IN ASEAN COUNTRIES

The projection shows that there will be significant increases in the level of final energy consumption in the ASEAN countries by all types of fleets, such as passenger cars, trucks, buses, and motorcycles. As electric vehicles penetrate into the fleets, the degree of reduction in the level of final energy consumption will be drastic. Figure 1 presents the level of final energy consumption by fleets and scenarios in 2040 in the ASEAN countries.

Figure 1: The Level of Final Energy Consumption by Fleets and Scenarios in the ASEAN Countries in 2040

(Unit: Mtoe)



Source: Li and Chang (2019).

Combining the effects of the introduction of EVs and higher fuel efficiency, the ASEAN anticipates a possible future with a lower level of final energy consumption in the road transport sector, which the APS with 30% of EV penetration shows. The introduction of EVs into the road transport sector typically proceeds by combining the road transport and the power sector. When considering the level of primary fossil fuel energy consumption in the power sector, the penetration of EVs actually may not contribute much to reducing the level of primary energy consumption if thermal power still dominates the power generation in the ASEAN countries by 2040. A higher penetration rate of EVs and a higher level of primary energy consumption in the road transport sector would be the case.

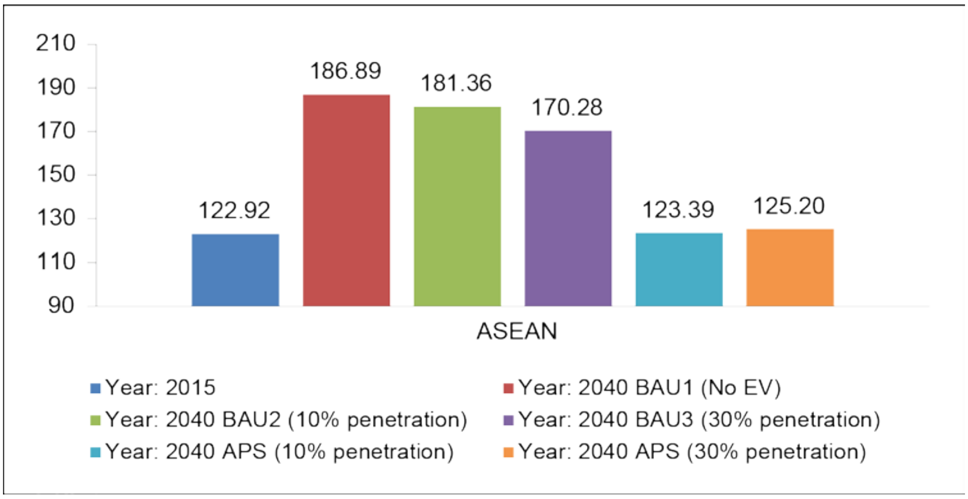
Such a finding is not surprising for two reasons. First, although an EV power train intrinsically has a high level of performance in fuel economy, the low efficiency of thermal power generation will mostly erode such an advantage if thermal power dominates the power sector. Second, the fuel economy of conventional vehicles in the BAU scenario is likely to improve by about 30%. In the APS scenarios, the fuel economy can improve by as much as 70% or more. Further application of conventional vehicles with improved fuel economy will actually contribute to a lower level of primary energy consumption than EVs (Li and Chang 2019).

The last two scenarios provide other interesting observations. The aggressive implementation of fuel economy in the ASEAN countries appears to promote EV penetration (Li and Chang 2019). The level of primary energy consumption in the road transport sector seems to be improving significantly, and the aggressive fuel economy appears to be the main driver. Figure 2 presents the level of consumption of fossil energy by scenarios in 2040 in the ASEAN. It shows that the AP case integrates renewable energy aggressively into the power sector. In the case of 30% penetration of EVs, the level of primary energy consumption will be higher than with only 10% of EV penetration for two reasons. First, in terms of energy efficiency, aggressive fuel economy results in a higher level of energy efficiency than EVs, so more EVs mean a higher level of primary energy consumption if all other things are equal. Second, EVs obtain their energy from a power grid, and fossil fuel-fired generation, such as coal and natural gas, still dominates the power grid. In such a case, higher losses in the conversion process of fossil fuels into electricity further erode the level of well-to-wheel energy efficiency of EVs.

Having noticed such a contradictory case, in which the level of primary energy consumption is increasing rather than decreasing, it would be interesting to examine what will happen if aggressive policies increase the integration of renewables into the power sector. The ASEAN will implement the policies by 2040, when the power generation sector in the ASEAN follows the assumptions that the APS scenario of the power sector outlook presents according to the Economic Research Institute for ASEAN and East Asia (ERIA) (2016). With the adoption of aggressive policies to improve the integration of renewables into the power sector of the ASEAN, the penetration of EVs will help to reduce the level of primary energy consumption in the ASEAN's road transport sector. First, without the achievement of the aggressive fuel economy in the ASEAN, the 30% penetration of EV appears to be the best policy target. Second, with the achievement of the aggressive fuel economy in the ASEAN, only the penetration level of 10% appears to be the ideal level for the penetration of EVs.

Figure 2: Fossil Energy Consumption by Scenarios in 2040 in ASEAN

(Unit: Mtoe)



Source: Li and Chang (2019).

The introduction of EVs into the ASEAN countries appears to make the ASEAN's final energy consumption in the road transport sector decrease significantly in the alternative scenarios of 2040 compared with the BAU scenario of 2040. However, taking into consideration the level of primary energy consumption in the power sector to charge EVs, the level of primary energy consumption in the ASEAN's road transport sector actually appears to be higher than that in the BAU scenario of 2040. This is mainly caused by the expectation that fossil fuels will generate a majority of the electricity in the ASEAN and that there will be huge losses during the conversion process from fossil fuels into electricity (Li and Chang 2019). When considering the large-scale introduction of EVs into the ASEAN countries' road transport sector, the large-scale introduction of renewables should either precede EVs or at least occur simultaneously with EVs. It is worth noting that, due to the lack of availability of data, this study makes many assumptions. Such assumptions need further testing or the building of sub-models to incorporate those assumptions to obtain more accurate estimations in future studies.

5. ELECTRO MOBILITY AND THE URBAN AIR QUALITY

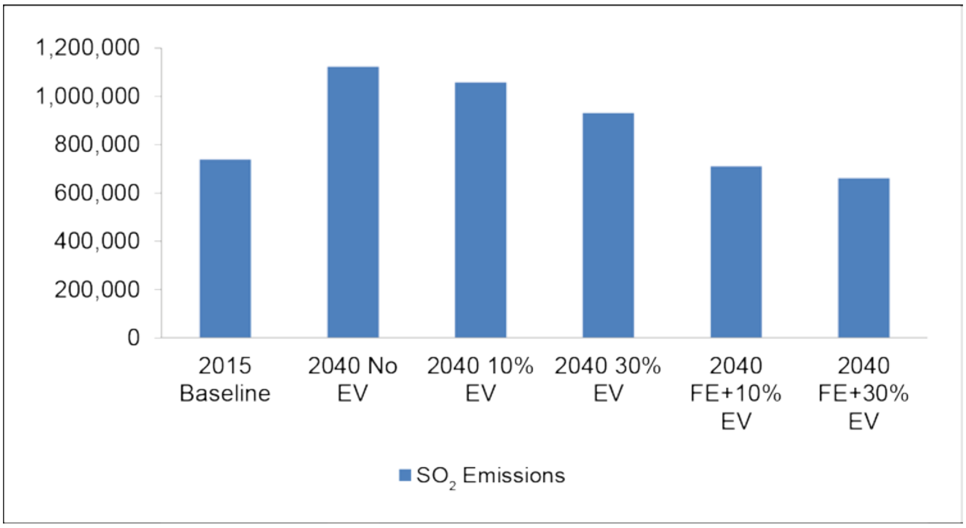
When implementing the electrification of the road transport sector in the ASEAN, the level of primary energy consumption appears to decrease under aggressive APS scenarios. Taking SO_2 emissions as an indicator of the urban air quality, this study shows how the electrification of the road transport sector could affect the urban air quality in the ASEAN in 2040.

Figure 3 presents the level of SO_2 emissions in 2040 by scenarios. As expected, the no-EV case shows that the urban air quality in 2040 could be far worse than in 2015 as the expectation is that the level of SO_2 emissions will actually increase. The cases of 10% EVs and 30% EVs appear not to improve the urban air quality either, as the higher level of electrification in the road transport sector is likely to drive the level of primary energy consumption to increase. Electricity generated from fossil fuel sources can meet the higher demand for electricity due to the higher penetration of electric mobility, eventually increasing the primary energy consumption.

With the implementation of an aggressive fuel mix policy for power generation with 10% penetration of electric mobility, as the scenario of "FE plus 10% EV" shows, the urban air quality in 2040 can be better than that in 2015. With an aggressive fuel mix policy and

30% penetration of electric mobility, as the scenario of “FE plus 30% EV” shows, the urban air quality can be far better than in 2015.

Figure 3: Sulfur Dioxide (SO_2) Emissions by Scenarios
(Unit: Tons)



Source: Authors’ calculation.

The penetration of electric vehicles contributes to lower SO_2 emissions, and higher fuel efficiency standards seem to contribute even more. In addition, if countries introduce more renewable energy into the power generation sector, SO_2 emissions will fall far more.

Apart from the economic and energy-related benefits, people expect electric mobility to bring environmental benefits, such as improvements in the urban air quality. The current study, however, shows that achieving such environmental improvements with electric mobility alone appears to be very difficult. It suggests that a more aggressive policy toward the fuel mix in power generation is necessary, together with an electric mobility policy.

6. CONCLUSION

This study links energy insecurity to public health through the analysis of the changes in urban air quality due to the penetration of electric mobility in the ASEAN countries in 2040. It finds that electric mobility can decrease the primary energy consumption in relation to sulfur dioxide emissions from vehicles and power generation.

It calculates the amount of sulfur dioxides by scenarios and finds that two scenarios with an aggressive fuel mix policy for power generation will decrease sulfur dioxide emissions compared with the no EV scenario and even 2015. This indicates that electric mobility (but only with an aggressive fuel mix policy for power generation) can alleviate the status of energy insecurity by improving the urban air quality.

The high penetration of electric mobility in the ASEAN countries can decrease the level of final energy consumption compared with the case of no electric mobility. For the level of primary energy consumption, however, electric mobility alone will not bring much of a decrease. Implementing electric mobility with an aggressive fuel mix policy for power generation appears to decrease the level of primary energy consumption compared with the no electric mobility scenario, and it could be lower than the base case scenario.

The study understands energy insecurity in the framework verifying the consequences of less access to energy for public health. Electric mobility can improve the urban air quality by decreasing the amount of harmful air pollutants, such as sulfur dioxides. High penetration of electric mobility with an aggressive fuel mix policy for power generation, as shown in the scenario of "FE+30% EV" in 2040, can decrease the amount of sulfur dioxides emitted in cities so that the urban air quality improves, in turn alleviating the problem of energy insecurity.

REFERENCES

Afif, C., C. Chelala, A. Borbon, M. Abboud, J. Adjizian-Gerard, W. Farah, C. Jambert, R. Zaarour, N.B. Saliba, P.E. Perros, and T. Rizk. 2008. "SO_2 in Beirut: Air Quality Implication and Effects of Local Emissions and Long-Term Transport." *Air Quality Atmospheric Health* 1: 167–78.

Alpopi, C., and S.E. Colesca. 2010. "Urban Air Quality: A Comparative Study of Major European Capitals." *Theoretical and Empirical Researches in Urban Management* 6: 92–107.

Asian Development Bank (ADB). 2006. *Country Synthesis Report on Urban Air Quality Management*: *Philippines*. Manila, the Philippines.

Barkley, M.P., G.G. Abad, T.P. Kurosu, R. Spurr, S. Torbatian, and C. Lerot. 2017. "OMI Air-Quality Monitoring over the Middle East." *Atmospheric Chemical Physics* 17: 4687–709.

Buckley, S.M., and M.J. Mitchell. 2011. "Improvements in Urban Air Quality: Case Studies from New York State, USA." *Water, Air, & Soil Pollution* 214: 93–106.

Economic Research Institute for ASEAN and East Asia (ERIA). 2016. *Energy Outlook and Energy Saving Potential in East Asia 2016*, edited by Shigeru Kimura and Han Phoumin. Jakarta, Indonesia: Economic Research Institute for ASEAN and East Asia.

European Environmental Agency (EEA). n.d. *Assessment and Management of Urban Air Quality in Europe*. EEA Monograph no. 5. Copenhagen, Denmark.

Global Fuel Economy Initiative (GFEI) and International Energy Agency (IEA). 2017. *International Comparison of Light-Duty Vehicle Fuel Economy 2005–2015: Ten Years of Fuel Economy Benchmarking*. Working Paper 15. Paris, France: OECD/IEA.

Hasan, G., M.A.A. Kubaisy, A.A. Ali, N. Othman, and M.M. Hason. 2014. "Sulfur Dioxide (SO_2) Monitoring over Kirkuk City Using Remote Sensing Data." *Civil and Environmental Engineering* 4(5) 1000155.

Hernandez, D. 2013. "Editorial." *American Journal of Public Health* 103 (4): e32–4.

———. 2016. "Understanding 'Energy Insecurity' and Why It Matters to Health." *Social Science & Medicine* 167: 1–10.

Hosamane, S.N., and G.P. Desai. 2013. "Urban Air Pollution Trend in India—Present Scenario." *International Journal of Innovative Research in Science, Engineering and Technology* 2: 3738–47.

Ilyas, S.Z. 2007. "A Review of Transport and Urban Air Pollution in Pakistan." *Journal of Applied Science Environmental Management* 11: 113–21.

International Energy Agency. 2016. *Energy and Air Pollution*. World Energy Outlook: Special Report. Paris, France.

International Gas Union. 2016. *Case Studies in Improving Urban Air Quality*. Barcelona, Spain.

Khan, A., K.-H. Kim, J.E. Szulejko, R.J.C. Brown, E.-C. Jeon, J.-M. Oh, Y.S. Shin, and A.A. Adelodun. 2017. "Long-Term Trends in Airborne SO_2 in an Air Quality Monitoring Station in Seoul, Korea, from 1987 to 2013." *Journal of the Air & Waste Management Association* 67: 923–32.

Kosan, Z., D. Kavuncuoglu, E. Cahkoglu, and E.B. Yerli. 2018. “Evaluation of Air Pollution by PM_{10} and SO_2 Levels in Erzurum Province, Turkey: Descriptive Study.” *Journal of Surgery and Medicine* 2: 265–8.

Li, Y., and Y. Chang. 2019. “Road Transport Electrification and Energy Security in the Association of Southeast Asian Nations: Quantitative Analysis and Policy Implications.” *Energy Policy* 129: 805–15.

Mansouri, B., E. Hoshyari, and A. Mansouri. 2011. “Study on Ambient Concentration of Air Quality Parameters in Different Months in Shiraz City, Iran.” *International Journal of Environmental Science* 1: 1440–7.

National Academy of Engineering and National Research Council. 2008. *Energy Futures and Urban Air Pollution*: *Challenges for China and the United States*. Washington, DC: National Academies Press.

Nichols, B., K.M. Kockelman, and M. Reiter. 2015. “Air Quality Impacts of Electric Vehicle Adoption in Texas.” *Transportation Research Part D* 34: 208–18.

Nikolic, D., N. Milosevic, I. Mihajlovic, Z. Zivkovic, V. Tasic, R. Kovacevic, and N. Petrovic. 2010. “Multi-criteria Analysis of Air Pollution with SO_2 and PM_{10} in Urban Area around the Copper Smelter in Bor, Serbia.” *Water, Air, and Soil Pollution* 1–4: 369–83.

Nopmongcol, U., J. Grant, E. Knipping, M. Alexander, R. Schurhoff, D. Young, J. Jung, T. Shah, and G. Yarwood. 2017. “Air Quality Impacts of Electrifying Vehicles and Equipment across the United States.” *Environmental Science & Technology* 51: 2830–7.

Nowak, A., D.E. Crane, and J.C. Stevens. 2006. “Air Pollution Removal by Urban Trees and Shrubs in the United States.” *Urban Forestry Urban Greening* 4: 115–23.

Perera, F. 2018. “Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist.” *International Journal of Environmental Research and Public Health* 15: 16.

Peters, I.M., S. Karthik, H. Liu, T. Buonassisi, and A. Nobre. 2018. “Urban Haze and Photovoltaics.” *Energy and Environmental Science* 11: 3043–54.

Prescott, G.J., G.R. Cohen, R.A. Elton, F.G.R. Fowkes, and R.M. Agius. 1998. “Urban Air Pollution and Cardiopulmonary Ill Health: A 14.5 Year Time Series Study.” *Occupational Environmental Medicine* 55: 697–704.

Qin, Y., F. Wagner, N. Scovronick, W. Peng, J. Yang, T. Zhu, K.R. Smith, and D.L. Mauzerall. 2017. “Air Quality, Health, and Climate Implications of China’s Synthetic Natural Gas Development.” *Proceedings of the National Academy of Sciences of the United States of America* 114: 4887–92.

Szyda, J., H. Wierzbicki, and A. Stoklosa. 2009. “Statistical Modelling of Changes in Concentrations of Atmospheric NO_2 and SO_2.” *Polish Journal of Environmental Studies* 18: 1123–9.

World Health Organization (WHO). 2000. *Guidelines for Air Quality*. Geneva, Switzerland.

———. 2005. *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulphur Dioxide*: *Global Update* 2005. Geneva, Switzerland.

World Resources Institute. 1998. *World Resources* 1998–99: *Environmental Change and Human Health*. Washington, DC.

Wuebbles, D.J., and S. Sanyal. 2015. “Air Quality in a Cleaner Energy World.” *Current Pollution Reports* 1: 117–29.

Xiao, K., Y. Wang, G. Wu, B. Fu, and Y. Zhu. 2018. “Spatiotemporal Characteristics of Air Pollutants in the Inland Basin City of Chengdu, Southwest China.” *Atmosphere* 9: 74.

Yang, J., and J. Schreifels. 2003. *Implementing SO_2 Emissions in China*. CCNM/GF/SD/ENV(2003)16/FINAL. OECD, Paris, France.